E-21.6RV

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High Efficiency Green Emitter

Jeff Nause, Bill Nemeth – Cermet, Inc.

Ian Ferguson – Georgia Institute of Technology

Program Goals

The goal of this program is to develop an efficient green nitride LED by integrating high quality ZnO substrate technology and state-of-the-art nitride epitaxy technology to address substrate, epitaxy and device limitations in the "green gap."

Benefits of the Program

- IP Free of Traditional Bottlenecks in US and Asia
- Highly Manufacturable
- Low Cost Approach
- Potential for Highly Efficient Light Sources

Why Nitrides on ZnO?

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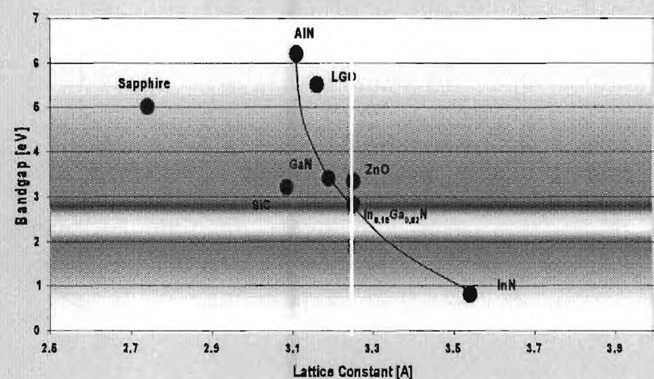

- ➢ZnO and Nitrides are Isomorphic
- ➢Same Crystallographic Space Group
- ➢ZnO is Lattice Matched to InGaN Composition

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Technical Objectives

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- ➢Develop truly lattice matched, low defect density (as low as 10^4 cm^{-2}) nitride emitter structures on ZnO substrates in the wavelength range of 555-585 nm, resulting in significantly reduced non-radiative recombination centers
- ➢ Demonstrate p-doping in high In composition nitride alloys, up to the lattice matched composition of 18% indium
- ➢Demonstrate hydrogen free MOCVD growth of nitrides, minimizing substrate / epitaxy interactions typical of heteroepitaxy.

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Additional Features of ZnO

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- Electrically Conductive for Vertical Current Devices
- Modulate Index of Refraction to Maximize Light Extraction
  - GaN = 2.5
  - ZnO = 2.2
  - Sapphire = 1.8
- Thermal Conductivity Significantly Higher than Sapphire
- Band Gap can be Modulated to Higher Energy
- Metallization and Processing is Known for ZnO

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Key Features of the Technology

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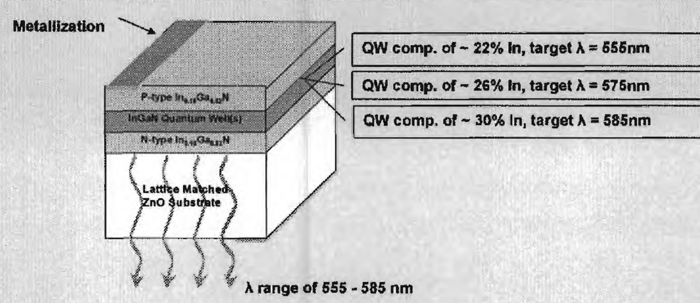

- Control Device Defects at the Substrate Level
- Reduce Cost Structure for LEDs;
  - Growth on Low Cost Substrates
  - Commercial, High Volume Epitaxy Approach
  - Enable Vertical Contact Geometry
- Enhance Performance;
  - Reduced Non-radiative Recombination Centers
  - Enhanced Optical Properties

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Phase I Project Objectives

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Phase I Work Plan Month	2	4	6	8
Task 1. Grow InGaN on ZnO a. ZnO Wafers Produced b. Lattice Matched Epitaxy c. Indium Fluctuation Control				
Task 2. Characterize Films				
Task 3. Defect Density Map of InGaN				
Task 4. Electrical Characterization of InGaN				
Task 5. P-doping Calibration of InGaN				
Task 6. Reporting	*	*	*	*

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- Phase I Results -
Cermet's ZnO Crystal Growth and Wafer Fabrication

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Cermet's Melt Growth Technology

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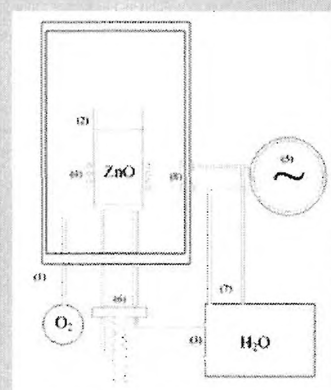
- Modified Bridgman process
  - Since ZnO melts at such a high temperature, radio frequency heating is used
  - Melt Containment Critical
- Precursors must be high quality to minimize unintentional doping
  - Process removes impurity concentration up to order of 10^4 parts per billion



Cermet's Melt Grown ZnO

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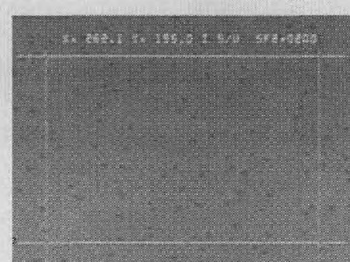
- Large Diameter Boule Capability
- Crystal Quality is Excellent
- Optical Quality is Excellent
- Very Smooth Surfaces Demonstrated



($10^4/cm^2$) Etch Pit Densities

Manufacturing Process Flow

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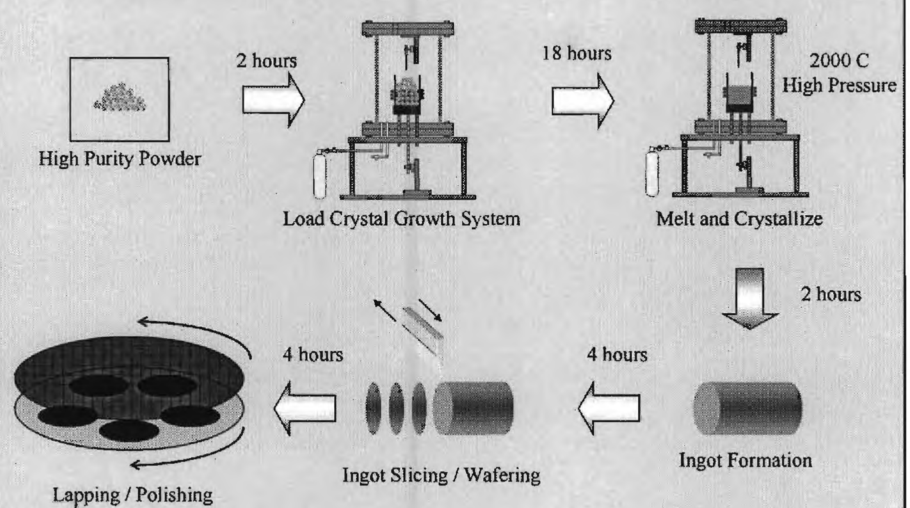

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Lapping, Polishing and Chemi-Mechanical Polishing

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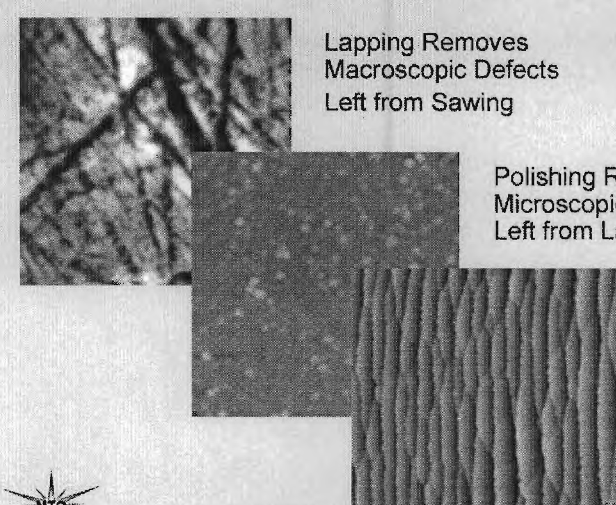
Finishing Process Removes Surface Damage from Previous Processing



Lapping Removes Macroscopic Defects Left from Sawing

Polishing Removes Microscopic Defects Left from Lapping

CMP Removes Nanometer / Atomic Level Defects Left from Final Polishing

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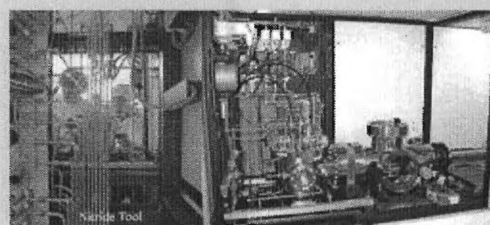
- Phase I Results -
Lattice Matched
InGaN on ZnO by MOCVD



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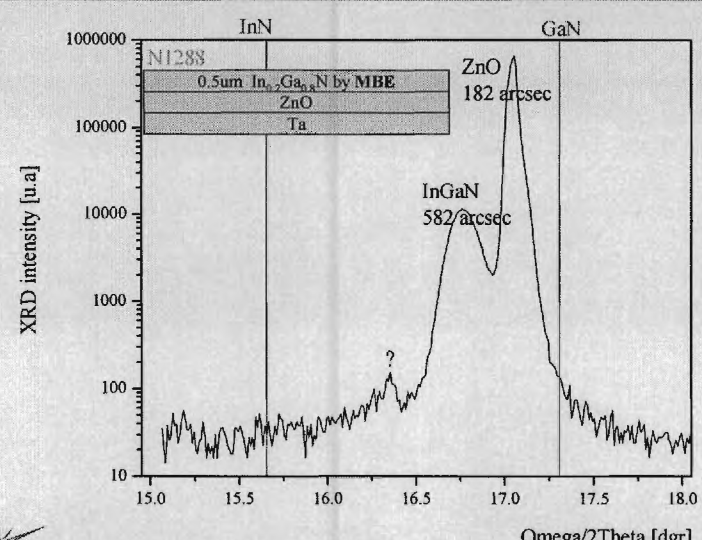
Nucleation Layers: InGaN on ZnO by MBE



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Structural Comparison of GaN-on-ZnO and GaN-on-Sapphire

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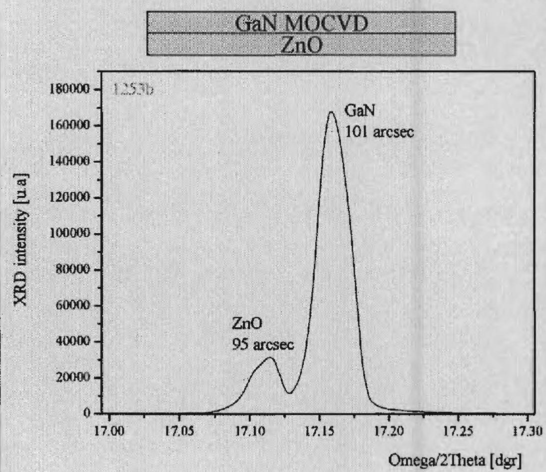

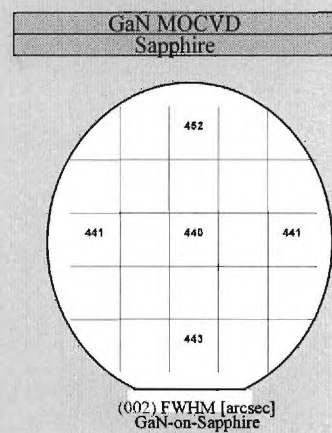

Control of In Fluctuations in InGaN on ZnO

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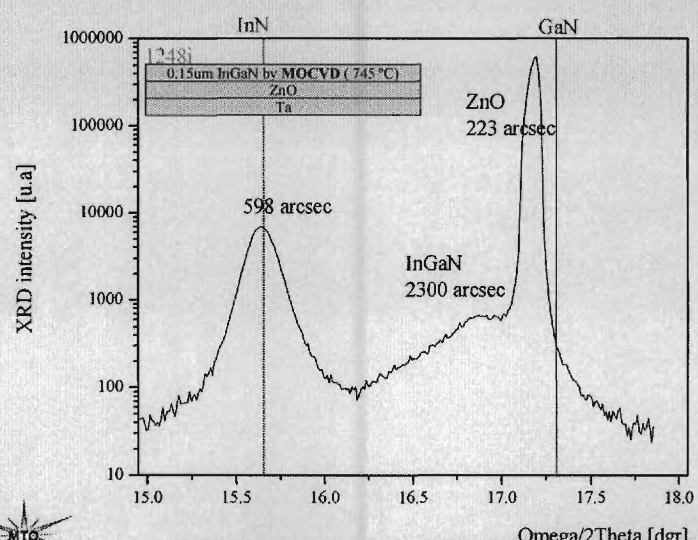

GaN / InGaN Structures on ZnO

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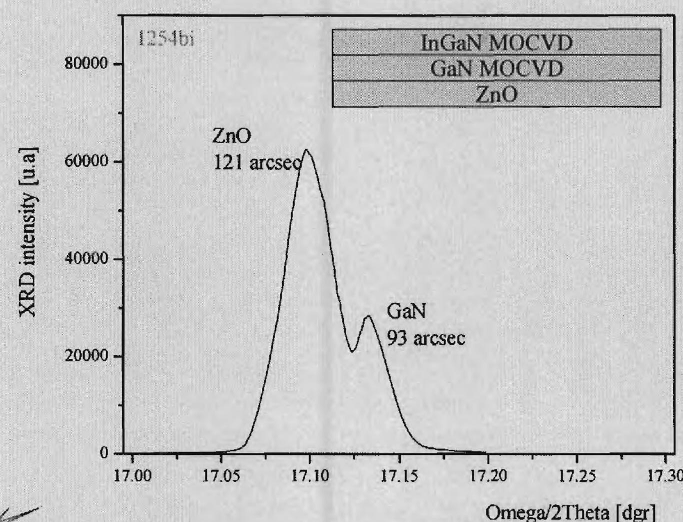

MQW InGaN / GaN on ZnO

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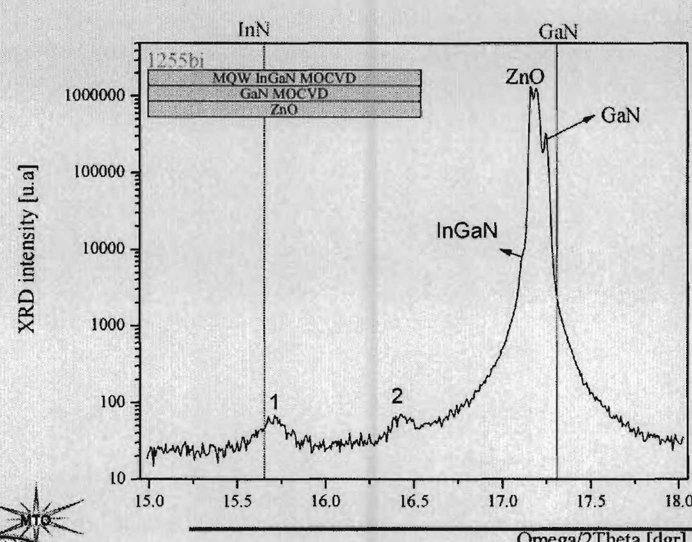

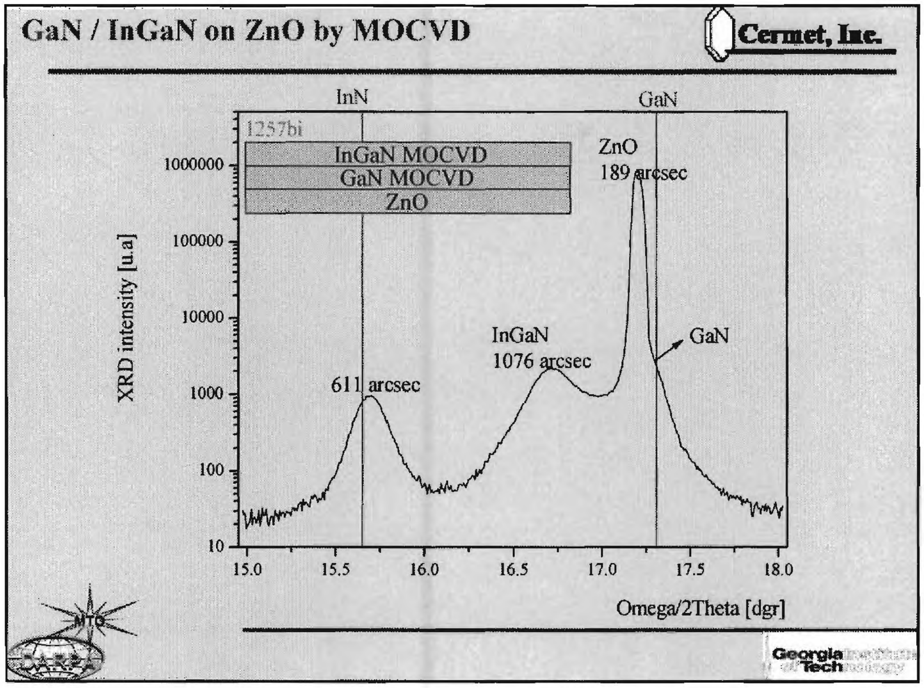
GaN / InGaN on ZnO by MOCVD
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InN
GaN
1257bi
InGaN MOCVD
GaN MOCVD
ZnO
ZnO
189 arcsec
InGaN
1076 arcsec
GaN
611 arcsec
XRD intensity [u.a]
Omega/2Theta [dgr]
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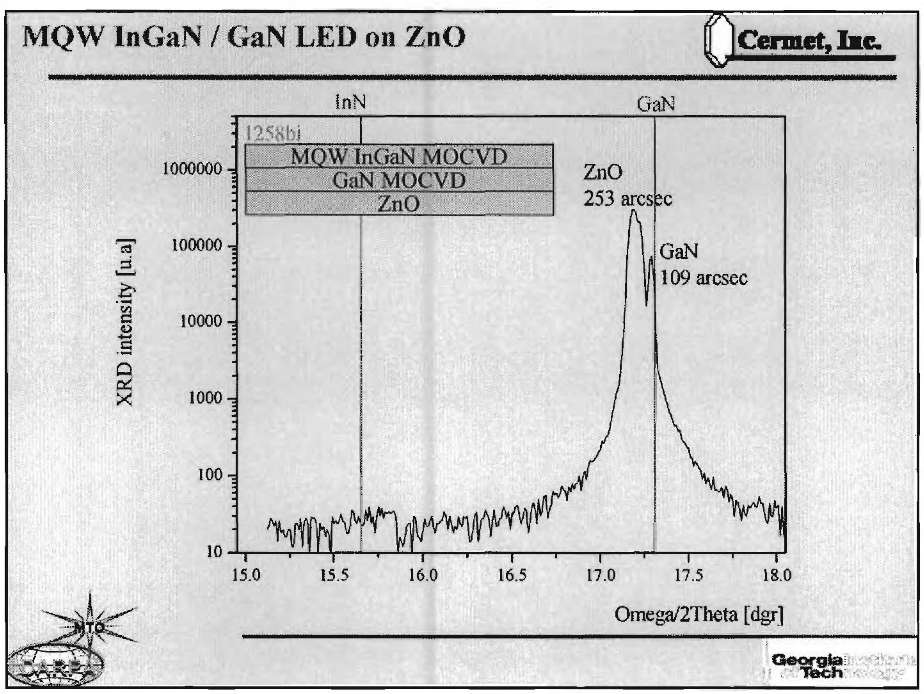
MQW InGaN / GaN LED on ZnO
Cermet, Inc.
InN
GaN
1258bi
MQW InGaN MOCVD
GaN MOCVD
ZnO
ZnO
253 arcsec
GaN
109 arcsec
XRD intensity [u.a]
Omega/2Theta [dgr]
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Optical Properties of $In_{0.18}Ga_{0.82}N$ on ZnO

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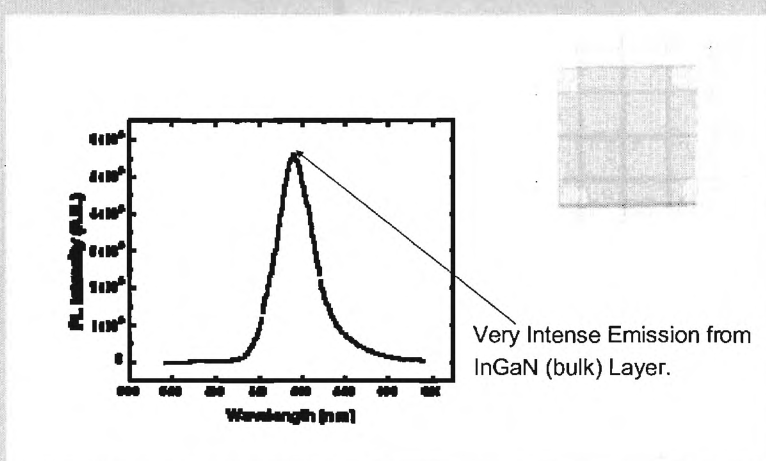

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Etch Pit Density Measurements

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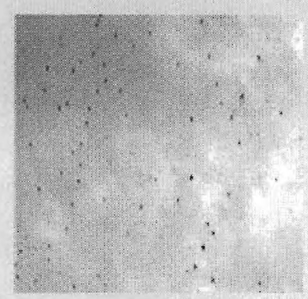

Etching Technique

- Solution: 85% H_3PO_4.
- Etch Temperature: 160° C
- Etch Times: 90-120 minutes

Counting Technique

- Etched Surfaces Observed 160x Optical.
- Random Areas Selected over the Entire Area of the Wafer
- All Etch Pits Contained in a Fixed Area were Counted

Result

- Avg. EPD for $In_{0.18}Ga_{0.82}N$ on ZnO = 1.2×10^4 cm^{-2}

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Roughness Data for MOCVD Epi on ZnO

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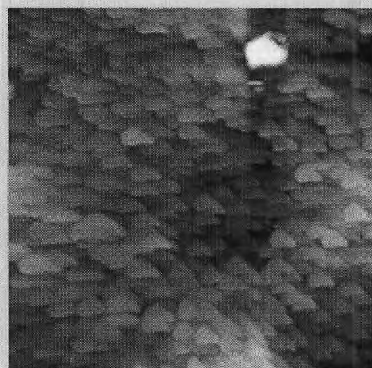
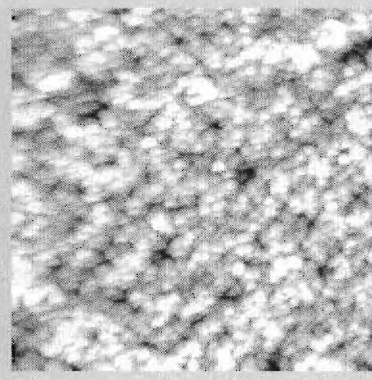
1248i	1249i
	
Roughness = 8.87 nm	Roughness = 11.85 nm

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Tentative Phase II Objectives

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Major Project Tasks and Milestones	Project Time (Months)							
	3	6	9	12	15	18	21	24
Task I. Production Grade 50 mm Substrates								
Elimination of Low-Angle grain boundaries								
<4? (rms) surface roughness								
Improved Crystalline Quality								
Improve orientation Accuracy (to +/-0.1°)								
Task II. Process Refinement of Lattice Matched InGaN Epitaxy								
Optimize deposition parameters for epitaxial growth								
Characterization for Lattice match and In composition								
Doping Calibration in InGaN, with p-type dopant ~ $10^{19}/cm^3$								
Electrically Characterize Films								
Task III. Device Fabrication								
Demonstrate Low Defect LED								
Develop SSL Source								
Demonstrate Color Mized White LED								

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